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Enhancing renewable and sustainable energy development based on an options-based policy evaluation framework: Case study of wind energy technology in Taiwan

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A B S T R A C T

Global warming and climate change have shifted the focus of industrial development towards low-carbon renewable energy (RE), as evidence by global efforts to develop RE-based sustainable energy policies. However, the generally cost-ineffective nature of RE investments explains continued governmental subsidies and draft assistance measures to encourage related industrial development, reduce research and development (R&D) costs, and increase innovativeness. Besides measures to accelerate supply and reduced demand for energy, sustainable energy policies must enact thoroughly planned legal and regulatory mechanisms. Notable examples of establishing a legal basis for a low-carbon society in Taiwan include the Energy Management Act, Renewable Energy Development Bill, Greenhouse Gas Reduction Act (Draft), and Energy Tax Act (Draft). However, such legislative efforts occasionally conflict or compete with each other, warranting further integration. Additionally, RE technologies are characterized by high R&D costs, long-term planning, and high investment risks. Therefore, based on global trends in wind power development and related policy planning, this study analyzes the feasibility of implementing management strategies in the development process and the correlations between such strategies. Additionally, the achievements, polices, functions, mechanisms, promotion measures, and future plans for related renewable and sustainable energy laws in Taiwan is thoroughly reviewed. An options-based policy evaluation framework is also constructed based on governmental administrative considerations. Moreover, the characteristics of options that lead to unforeseen circumstances during the planning of RE development policies are discussed, allowing us to derive real-time response measures with a decision-making value. Results of this study provide a valuable reference for governmental efforts to evaluate the merits and limitations of related policies concisely, ultimately facilitating the formulation of RE development policies.

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1. Introduction

The potential threats that energy shortages, global warming, and climate changes pose to society explain why energy policies worldwide increasingly focus on developing renewable energy (RE). Viewed as a highly effective means of conserving energy, RE also stresses reducing carbon emissions and decelerating climate change. For instance, the Obama Administration in the United States initiated a "New Green Deal" that focuses on developing green wind power, solar power, waste disposal, and water resource industries. Requiring an initial investment of approximately US$700 billion, the program hopes to eventually reduce carbon dioxide emission levels by 5 billion tons and create 5 million jobs in the green energy sector. Besides resolving high unemployment in the United States, this program will also hopefully prevent further deterioration of the global climate. While striving to promote RE, the Taiwan Government introduced the "Low Carbon Homeland" [1] program at the 3rd National Energy Conference in 2009. The Ministry of Economic Affairs (MOEA) proposed the "Dawn of the Green Energy Industry Program" [2] also in 2009, and approved the "Renewable Energy Development Bill" [3] in June 2009. Above actions reflect the determination of Taiwan in promoting the development of RE, increasing energy diversification, upgrading environmental quality, stimulating relevant industries, and furthering sustainable development island wide.

As is forecasted, global energy demand will continuously increase, with RE already growing in use. Despite the lack of a consensus at the 15th Conference of the Parties (COP15) of the UN Copenhagen Climate Summit at the end of 2009 over carbon dioxide emission reduction targets, participating countries proposed various emission reduction targets after the conference. Although lacking a binding force, these targets clearly indicate that the many industrialized countries have devoted their efforts to developing RE sources that benefit environmental sustainability. RE is thus an increasingly important alternative energy source. However, sources of RE and electricity generation methods differ from those based on non-renewable fossil fuel-based energy (NRE). Among the many uncertainties that affect RE development include natural conditions, fluctuating fossil fuel prices, maturing electricity generation technology, and national policy planning. Closely examining successful RE initiatives in other countries reveals a three-stage development phase: technology research and development (R&D) and demonstration phase, market development phase, as well as long-term development phase. Success of this undertaking largely depends on governmental policy support and a relevant legal basis during the early developmental period [4–11]. Nevertheless, governmental subsidies are insufficient. Investment firms must ultimately adopt innovative utilization methods and technologies, capacity expansion to achieve economies of scale, and internalization of the external costs of energy use if they are to fill the cost gap between RE and NRE, thereby enabling RE to compete with NRE in open markets.

The energy policy in Taiwan focuses on developing sustainable energy, energy conservation and emission reduction practices, ultimately achieving a low-carbon society. Additionally, relevant legislative action largely consists of legislative tasks related to implementing four energy laws [12–16]. The Energy Management Act and Renewable Development Energy Bill were passed in 2009, while the Greenhouse Gas Reduction Act and Energy Tax Act are still in draft form. However, further integration is required to resolve conflicts in policy objectives. Tables 1 and 2 as well as Fig. 1, show each law's regulatory framework, goals, functions, and duties, as well as their connection.

Additionally, advances in RE technology are limited by high R&D cost and difficulty of investment recovery, long and deferrable planning processes, high investment risks and uncertain returns, as well as the independence of decision makers to invest freely. Policy makers should thus utilize their managerial flexibility to adjust their policies as deemed appropriate in order to ensure that RE development policies reach their policy targets. Given these circumstances, this study analyzes the feasibility of management strategies in the development process and the correlations between those strategies by observing RE development and policy planning in major industrialized countries. Taiwan's RE development process, current situation, and incentive measures are reviewed to identify major factors that must be considered when evaluating RE development policies. Additionally, the theoretical approach of real options pricing is adopted to construct an options-based policy evaluation framework for RE development that reflects administrative considerations in government. The proposed framework's options allow for unforeseen factors affecting RE development policies, allowing us to derive real-time response measures with a decision-making value. Results of this study provide a valuable reference for governmental efforts to evaluate the merits and limitations of related policies concisely, ultimately facilitating the formulation of RE development policies.

2. Development policy and strategy planning of renewable energy: case study of wind energy technology

This section describes wind power development and policy planning in European and North American countries as well as in Taiwan to analyze the feasibility of implementing management strategies in the development process and the correlations between those strategies. When new information regarding potential commercial opportunities becomes available to investment markets, corporate investment decision makers generally formulate real-time strategies to effectively respond to new information and obtain decision-making value. Trigueros [19] classified the strategies devised by decision makers to respond to new information as (1) strategies to defer, which consist of waiting until sufficient information is available from the market or competitors before reaching an investment decision; (2) strategies to abandon, which view investment decisions as multi-stage management processes, and acquire information in each stage to determine the actions in the next stage and allow decisions involving whether to continue or halt implementations to be made; (3) strategies to expand, which rely on market demand to determine whether to increase investment or invest in further projects; (4) strategies to contract, which may adjust the amount of investment, depending on a favorable market situation; and (5) strategies to switch, which allow changes in an asset operating model in order to transfer investment to another project with a higher investment value.

Closely examining wind power development policy planning in Taiwan and that in European and North American countries [9,14,20] reveals that governments have adopted abandonment strategies, expansion strategies, and continuing development strategies in their wind power development policies at different points in time. These governments have effectively responded to market changes to ensure that their RE development policies yield

Table 1
Legislative framework, goals, and functions of the four energy laws.

Statute	Legislative framework	Goal	Function
Renewable Energy Development Bill	1. General principles	1. Extend renewable energy use	1. Development of clean energy
	2. Promotional goals	2. Diversify energy sources	2. Guaranteed purchase of green power
	3. Establishment of a renewable energy development fund	3. Improve environmental quality	
	4. Provision of incentives and subsidies for the installation of renewable energy equipment	4. Stimulate the development of relevant industries	
	5. Purchase and subsidization of power generation		
	6. Administrative assistance		
	7. Penalties and supplementary provisions		
Energy Management Act	1. General principles	1. Strengthen management of energy	Promotion of energy conservation measures, energy development, and use of assessment standards
	2. Determination of energy development outline regulations	2. Promote rational and effective energy use	
	3. Establishment of an energy research and development fund		
	4. Establishment of an energy audit system		
	5. Installation of gas and electric cogeneration equipment and compulsory regulations		
	6. Energy efficiency standards for energy products, vehicles, tools, and new buildings		
	7. Energy development and use of assessment criteria		
	8. Penalties and supplementary provisions		
Greenhouse Gas Reduction Act (Draft)	1. General principles	Mitigate global climate change, reduce greenhouse gas emissions, jointly fulfill the nation's responsibility to protect the world environment, and achieve sustainable development	To establish greenhouse gas reduction capabilities and implement substantive reduction
	2. Duties and powers of government agencies		
	3. Establishment of a greenhouse gas reduction adaptation fund		
	4. Reduction strategies		
	5. Education and awareness		
	6. Penalties and supplementary provisions		
Energy Tax Act (Draft)	1. General principles	1. To promote the rationalization of energy prices	1. Reflect the external costs of energy
	2. Tax items and tax amounts	2. To rationally reflect the production and social costs of energy use	2. Raise energy use efficiency
	3. Taxation procedures		
	4. Penalties and supplementary provisions		
	5. Accompanying measures		

Source: [17,18].

Table 2
Comparison of energy conservation and carbon emission reduction responsibilities under the four energy laws.

Policy instrument	Item	Renewable Energy Development Bill	Energy Management Act	Greenhouse Gas Reduction Act (Draft)	Energy Tax Act (Draft)
Goal	Reduction goal	×	×	▲	×
	Promotion goal	•	×	×	×
Responsibilities	Government responsibilities	•	•	•	•
	Industry responsibilities	•	•	•	•
Fiscal/economic instruments	Incentives and subsidies	•	•	•	×
	Expenses	•	•	•	×
	Taxation	×	×	×	•
	Total emission controls and emissions trading	×	×	•	×
Control instruments	Purchase of green electricity	•	•	×	×
	Formulation of standards	×	•	•	×
Voluntary agreements	Voluntary reduction	×	×	•	×
Policy procedures	Education and awareness	×	×	•	×
R&D and demonstrations	Research and development	•	•	•	×
	Demonstration projects	×	×	•	×
Accompanying measures	×	•	•	•	•

Source: [17,18].
Note: Entries with an • indicates such measures exist; × indicates that such measures do not exist; ▲ indicates that that it is still uncertain whether there will be such measures.

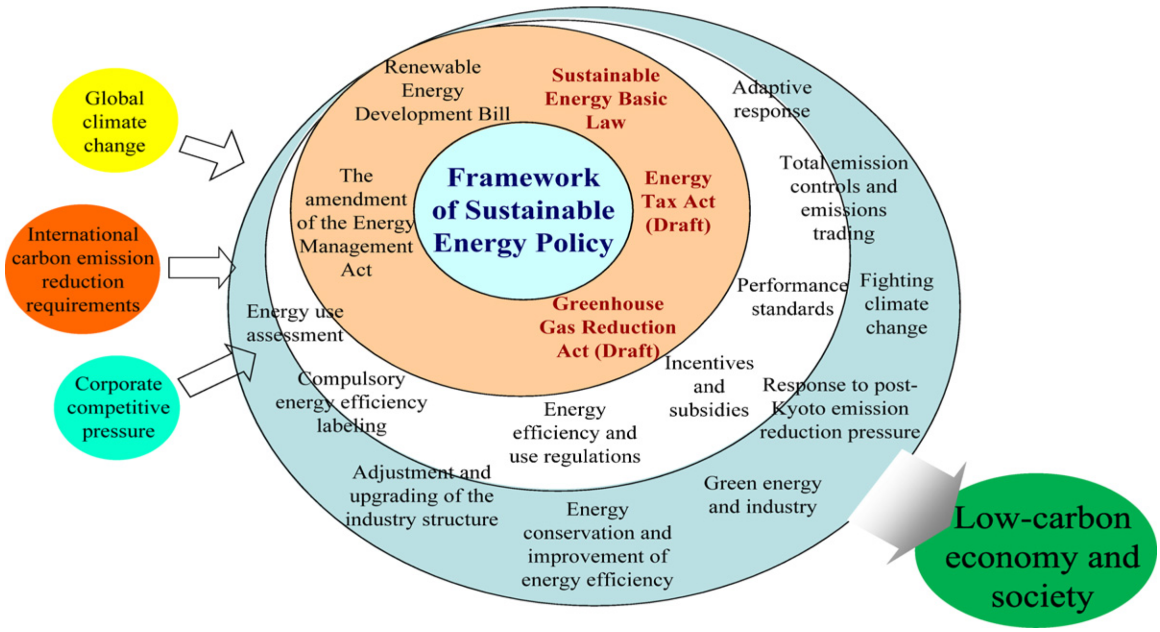

Fig. 1. Four energy laws and their linkage with a low-carbon economic and society.

the maximum benefit (Table 3). This study thus assumes that RE development is an investment policy plan and also views governmental agencies as policy strategy drafters and R&D funding providers. Private enterprises can also be viewed as R&D departments and recipients of governmental R&D funding. Governments can adopt expansion strategies, contract strategies, delaying strategies, or switch strategies according to market and technological conditions. Real options analysis (ROA) is also performed to consider uncertainty, risk, and management flexibility when drafting RE development policies, providing a valuable reference for the Taiwan government to devise an effective RE development policy.

Table 3
Development policy planning for wind energy in major industrialized countries.

Country	Year	Policy planning item	Strategy
USA	1978	Issuance of the Public Utilities Regulatory Policy Act Implementation of the Tax Credit for Renewable Energy Production	Expansion
	1985	Tax Credit for Renewable Energy Production revoked	Abandonment
	1992	Issuance of Energy Policy Act Implementation of new Tax Credit for Renewable Energy Production	Expansion
	1999	Extension of Energy Policy Act Issuance of the Regional Renewable Energy Quota Act	Expansion Growth
	2002	Extension of the new Tax Credit for Renewable Energy Production	Growth
	2009	Issuance of new Energy Policy Act	Expansion
Denmark	1979	Issuance of the Wind Turbine Subsidy Act	Expansion
	1985	Proportional power purchase prices	Expansion
	1989	Revocation of the Wind Turbine Subsidy Act	Abandonment
	1990	Offshore wind power research	Expansion
	1993	Purchase of power at fixed prices	Growth
	1996	Energy 21 By-law	Expansion
	1999	Deregulation of power market	Expansion
	2003	Revocation of power purchase regulations Renewable energy certificates	Abandonment Expansion
Germany	1989	100 MW wind power program announced	Expansion
	1990	100 MW wind power program revoked	Abandonment
	1991	250 MW wind power program announced Issuance of Electricity Feed Law Issuance of Electricity Feed Law	Expansion
	1996	Revocation of 250 MW wind power program	Abandonment
	2000	Issuance of the Act on Granting Priority to Renewable Energy Sources	Expansion
	2004	Revision of the Act on Granting Priority to Renewable Energy Sources	Growth
Taiwan	1980	150 kW wind turbine prototype development program	Expansion
	1990	Revocation of 150 kW wind turbine prototype development program	Abandonment
	2000	Issuance of the Regulations Governing Subsidies for the Establishment of Wind Power Generation Demonstration Systems	Expansion
	2003	Issuance of the Taipower renewable energy purchase scheme	Expansion
	2004	Revocation of the Regulations Governing Subsidies for the Establishment of Wind Power Generation Demonstration Systems Revision of the Taipower renewable energy purchase scheme	Abandonment Expansion
	2007	Issuance of the Stage I Offshore Wind Power Generating Plant Establishment Program	Expansion
	2009	Issuance of the dawn of the green energy industry program	Expansion
	2009	Issuance of the Renewable Energy Development Bill	Expansion
	2010	Issuance of Feed-in tariff level for various types of renewable energy technologies	Growth

Table 4
Development mechanism of renewable energy policies in Taiwan.

Stage	Year	Event	Policy strategies and features
Economic development stage	1968	Approval of Taiwan area energy development principles	1. Development of energy technology and promotion of economic growth.
	1970	Establishment of the MOEA's Energy Policy Review Committee	2. Stabilization of energy supply.
	1973	Taiwan Area Energy Policy	3. Enhancement of energy efficiency.
	1979	1st revision of the Taiwan Area Energy Policy Establishment of Energy Commission, MOEA	4. Development of energy enterprises.
	1984	2nd revision of the Taiwan Area Energy Policy	5. Emphasis on sustainable development.
	1990	3rd revision of the Taiwan Area Energy Policy	6. Strengthening of research and development; promotion of education and awareness
	1996	4th revision of the Taiwan Area Energy Policy	
Sustainable development stage	1998	1st National Energy Conference	Apart from six major policy directives connected with economic development, Taiwan has added environmentally sustainable energy policy planning.
	1999	New Energy and Clean Energy Research and Development Program	
	1999	Revision of Article 7 of the Electricity Act	
	2000	Five-year Renewable Energy Demonstration and Extension Project	
	2001	National Economic Development Conference	
	2002	Executive Yuan Challenge 2008 – National Development Plan – Renewable Energy Development Program	
	2002	1st National Energy Conference	
	2002	Renewable Energy Development Bill (Draft)	
	2003	Nuclear-free Homeland Action Plan	
	2004	Operating Guidelines for the Taipower renewable energy purchase scheme	
	2004	Establishment of the Bureau of Energy, MOEA	
Sustainable energy stage	2005	7th National Science and Technology Conference	Active and balanced promotion of the 3Es: energy security, environmental protection, and economic growth; the development of stable, efficient, and clean low-carbon energy technologies.
	2005	25th Science and Technology Advisory Board Meeting of the Executive Yuan	
	2005	2nd National Energy Conference	
	2006	MOEA Green Industry Plan	
	2007	Executive Yuan Industrial Technology Strategy Conference	
	2008	2008 Global Industry Technology Summit Forum	
	2008	Framework of Taiwan's Sustainable Energy Policy	
	2009	2009 National Energy Conference	
	2009	Dawn of the green energy industry program	
	2009	Renewable Energy Development Bill	
	2010	Feed-in tariff level for various types of renewable energy technologies	

3. The development of Taiwan's renewable energy policy, current status, and incentive measures

Governments worldwide devote considerable resources to conserving energy and reducing carbon emission levels. Taiwan's energy policies have evolved in three main stages (Table 4). Beginning with the sustainable energy policy stage, Taiwan has successively implemented the "1st National Energy Conference," "Five-year Renewable Energy Demonstration and Extension Project," "Renewable Energy Development Bill," "Nuclear-free Homeland Action Plan," "Executive Yuan Industrial Technology Strategy Conference," "Low-carbon Homeland," and "Dawn of the Green Energy Industry Program." Consequently, Taiwan's policy directions and developmental goals have become increasingly evident, with an implementation framework subsequently taking shape.

To facilitate the development of an effective utilization of RE, the Bureau of Energy, MOEA has formulated RE development goals and incentive policies based on the three principles of overall economic competitiveness, national security, and environmental protection. In addition to considering the potential capacity, technological maturity, and power generation costs of various forms of RE, as well as how RE development affects power prices and economic development, the above goals and policies strive to ensure that the ratio of RE does not deteriorate the stability of current power supplies and promote the development of the domestic RE industry. Tables 5–7 summarize Taiwan's goals and incentive measures. To encourage RE development, energy diversification, environmental quality, related industrial growth, and national sustainable development, the Taiwan government mandated the "Renewable Energy Development Bill" on July 8, 2009 [3]. According to the bill, the government may use measures such as the Feed-in tariff (FIT) and incentives demonstrations to stimulate the development of RE incentives. The bill attempts to promote the ambitious target to achieve approximately 6500–10,000 MW of energy from RE by 2025, which is equivalent to increasing Taiwan's accumulated installed capacity of power supply from RE to above 15%. As of July 2010, besides hydropower and biomass, Taiwan was still far from its RE goals [17]. Clearly, the development of RE in Taiwan, in addition to relying on government's heavy promotional efforts, will also require the government to collaborate with the private sector if the country's 2025 targets are to be met.

Taiwan's RE development incentive measures generally consist of equipment subsidies, special subsidies, power price subsidies, and financial incentives. Most funding for RE technology R&D either originates from the Bureau of Energy or comes in the form of the subsidized purchase of electricity from RE by the Taiwan Power Co. RE R&D is generally geared towards technology development

Table 5
Current status and future targets for renewable energy development in Taiwan.

Year renewables	July, 2010 Current status		2010 Future targets		2015		2025	
	Installed capacity (MW)	Rate (%)	Installed capacity (MW)	Rate (%)	Installed capacity (MW)	Rate (%)	Installed capacity (MW)	Rate (%)
Hydropower	1939	4.9	2168	5.7	2261	5.1	2500	4.5
Wind power	436	1.1	980	2.5	1480	3.4	2450	4.4
Solar photovoltaics	11	0.0	31	0.1	320	0.7	2000	3.6
Geothermal	–	–	–	–	10	0.0	150	0.3
Biomass + waste power	814	2.05	741	1.9	850	1.9	1400	2.5
Ocean energy	–	–	–	–	1	0.0	200	0.4
Total	3200	3910	4922	8700				
Target share for renewable energy in terms of installed capacity of the total power generation		8.05		10.2		11.1		15.7

Source: BOEMOEA [17].

and technology extension issues. However, because innovative, forward-looking RE technology R&D does not represent mainstream R&D efforts, little long-term support is available for large R&D projects in this area. Additionally, because the domestic RE industry consists mainly of small and medium enterprises (SMEs), this study recommended that the government increase funding for technology R&D funding, and encourage firms to apply for funding for technology R&D projects through the New Leading Product Development Program, industry technology development programs, or industry-academic collaboration programs in order to promote the establishment of localized RE technology. The government should further devise methods of encouraging major international firms to participate in collaborative R&D involving advanced technologies. As is anticipated, due to passage of the Renewable Energy Development Bill, the remaining energy-related laws will gradually be implemented, providing a comprehensive, long-term legal basis for RE subsidies. Furthermore, R&D alliances that share the resources of industry, universities, and research organizations will lead to the development of major RE industrial technologies and niche products.

4. Management flexibility and the real options analysis

The discounted cash flow method (DCF method) and payback period method are the traditionally adopted methods for evaluating the value of an investment plan. While pioneering the theory of interest and the value of time, Fisher [21,22] proposed the DCF method, which is extensively adopted to evaluate investments and real asset investment decisions. The DCF method includes the net present value method (NPV method) and internal rate of return method (IRR method). DCF analysis is characterized by its simple calculation and easily visualized logic. However, its analytical framework and assumptions are based on irreversible and non-deferrable investment. DCF is thus applicable only for evaluating short-term investment projects with low uncertainties. Given its limited flexibility, DCF is inappropriate for a fluctuating

Table 6
Renewable energy industry promotion measures in Taiwan.

Instrument	Incentive measures
Equipment subsidies	Solar Hot Water System Extension Incentive Guidelines (issued 2/6/2003) (revised 12/31/2004) Solar Power Generation Demonstration System Facility Subsidy Regulations (issued 3/6/2002) (revised 5/30/2005) Regulations Governing Subsidies for the Establishment of Wind Power Generation Demonstration Systems (issued 3/22/2000) (revoked 6/29/2004) Methane Generation System Demonstration Project Subsidy Operating Guidelines (issued 5/17/2008) Fuel Cell Demonstration Operating Certification Subsidy Operating Guidelines (issued 1/7/2009)
Special subsidies	Solar Hot Water System Extension Incentive Guidelines (issued 2/6/2003) (revised 12/31/2004)
Power price subsidies	General Waste Landfill Methane Generation Incentive Regulations (issued 1/22/2003) (revoked 12/31/2008) Operating Guidelines for the Taipower renewable energy purchase scheme (issued 11/11/2003) (revised 7/13/2004) (revised 1/6/2006) (revised 8/16/2010) Stage I Offshore Wind Power Generating Plant Establishment Program (issued 8/24/2007) Statute on the Renewable Energy Development Bill (issued 7/8/2009)
Financial incentives	Statute for Upgrading Industry (issued 4/24/1991) (revised 2/2/2005) (revoked 5/12/2010) Regulations Governing Application of Investment Tax Credits to Companies Purchasing Energy Conservation or New or Clean Energy-using Equipment or Technologies (issued 8/30/1995) (revised 12/22/2004) Industrial Research Promotion and Development Loan Regulations (issued 3/28/2006) Industrial Innovation Statute (issued 5/12/2010)

Source: BOEMOEA [17].

Table 7
Feed-in tariff level for various renewable energy technologies in Taiwan.

Type of renewable energy	Feed-in Tariff NTD/kWh[a]
PV System: 1–10 kWp[b]	11.1883
PV System: 10–500 kWp	12.9722
PV System: over 500 kWp	11.1190
On-shore Wind Power System: 1–10 kW	7.2714
On-shore Wind Power System: over 10 kW	2.3834
Off-shore Wind Power System	4.1982
Streamflow Hydropower	2.0615
Geothermal Power Generation	5.1838
Biomass Power Generation	2.0615
Waste Power Generation	2.0879
Other[c]	2.0615

Source: BOEMOEA [17].

[a] Calculation formula of Feed-in Tariffs for renewable electricity

(1) $Tariff = \frac{\text{Installation cost} \times \text{Capital Recovery Factor} + \text{Operation and Maintenance Cost}}{\text{Annual Electricity Sold}}$.

(2) $Capital\ Recovery\ Factor = \frac{\text{discount Rate} \times (1+\text{Discount Rate})^{\text{duration of purchase}}}{(1+\text{Discount Rate})^{\text{duration of purchase}} - 1}$.

(3) Operation and Maintenance Cost = Installation Cost × Percentage of the O&M Cost over Installation Cost.

[b] Considering the domestic project financing mechanism is not ready, PV systems with capacity between 1 and 10 kWp will be subsidized with NTD50,000/kWp under another incentive regulation.

[c] For equipment got full equipment grants from BOE of MOEA, the electricity generated by such equipments shall be wholesaled at NTD 2.0615 per kWh for 20 years.

investment climate [23,24]. Moreover, DCF method cannot reflect managerial flexibility in investment decisions efficiently, possibly underestimating the opportunity and actual value of an investment [19,25–27]. Table 8 summarizes the merits and limitations of the three assessment models.

The ROA concept originates from finance. While pioneering the real options valuation method, Myers [28] posited that profits created by cash flow generated from an investment originate from currently owned assets in addition to options for future investment opportunities. While refuting the underlying assumptions of traditional capital budgeting methods, this method seeks gains from deferring an irreversible investment expenditure (in contrast with the "now or never" proposition implicit in traditional NPV analysis). Hence, the options pricing theory of Black and Scholes [29] was applied to value non-financial or "real" investments planning and acquire real assets with learning and flexibility, such as multi-stage R&D and modular manufacturing plant expansion. In contrast with traditional valuation models of investment decisions, real options models can assess managerial flexibility. Trigeorgis and Mason [27] referred to the investment project value of an options value with managerial flexibility obtained as "expanded or strategic" NPV. This value is the sum of the traditional NPV and managerial flexibility value. Following the work of Myers, the ROA concept has been extensively adopted in the literature and can be broadly classified into seven types [30,31], i.e. option to defer, time-to-build option, option to alter operating scale, option to abandon, option to switch, option to growth and interaction among multiple real options. Each option is described briefly as follows.

Table 8
Merits and limitations of traditional assessment methods.

Method	Merits	Limitations
Net present value method	1. Time possesses value and reflects all cash flows.	1. Owing to a potential high uncertainty of the cash flow and discount rate forecasts, forecasting errors lead to erroneous results, and decision-making risk is relatively high.
	2. The magnitude of economic benefits from an investment plan is considered.	2. When different investment cases entail varying amounts of risk, the NPV method's use of the same lowest rate of return on investment to discount cash flow tends to lead to a bias; different discount rates should thus be adopted.
	3. NPV represents how an investment plan directly contributes to corporate value, and can accurately represent how it influences stockholder wealth.	3. The NPV method does not reflect high or low cost effectiveness.
	4. The principle of value additivity is compliant, implying that the sum total of a company's value equals the sum of the contributions of its individual independent investment plans.	
	5. Only the NPV method can obtain the optimal decision when an exclusive plan is selected.	
Internal rate of return method	1. Time also possesses value and reflects all cash flows.	1. Since the IRR is a rate, this method does not consider the amount of investment and magnitude of cash flow.
	2. The magnitude of economic benefit from an investment plan is considered.	2. It not considers the various compensations of individual investment cases.
	3. The profitability of an investment plan is expressed as a single rate (IRR), which can be compared with other rates.	3. Because IRR is an unknown, analysis may be difficult when an investment plan exceeds two periods in duration, while net cash inflow may occasionally be positive and occasionally negative.
	4. Profitability is expressed as a rate of return, and can be easily compared with the cost of funds.	4. It may yield an erroneous decision when evaluating an exclusive investment plan.
		5. It makes unreasonable assumptions about the rate of return on reinvestment.
		6. Under circumstances of abnormal cash flow, this method may calculate one or more IRR values that are not consistent with value additivity.
Payback period method	1. It is relatively simple and easy to calculate and understand.	1. Does not assess economic compensation.
	2. It allows the time when the cost of an investment plan is completely recovered to be determined.	2. Does not take the time value of currency into consideration; tends to underestimate payback periods.
	3. It is easy to calculate and understand, as well as capable of assessing the liquidity of an investment plan.	3. Has no absolute standard for determining what the payback period should be in order to obtain the investment plan with the most suitable liquidity rate.
		4. Does not consider whether the plan will still generate long-term cash flow after recovering cost.
		5. Does not consider the influence of the time value of currency (opportunity cost).

(1) *Option to defer*: Management holds a lease on (or an option to buy) land or resources. The lease can wait X years without exercise.
(2) *Time-to-build option*: Staging investments as a series of outlays creates the option to abandon the enterprise in midstream if new information is unfavorable. Each stage can be viewed as an option on the value of subsequent stages and valued as a compound option.
(3) *Option to alter operating scale, e.g., option to expand, option to contract, option to shut down and restart*: If market conditions are more favorable than expected, the firm can expand the production scale or accelerate resource utilization and, conversely, if conditions are less favorable. In extreme cases, production may be halted and restarted.
(4) *Option to abandon*: If market conditions decline severely, management can abandon current operations permanently and realize the resale value of capital equipment and other assets on second hand markets.
(5) *Option to switch input or output*: If prices or demand change, management can adjust the output mix of the facility (product flexibility). Alternatively, the same outputs can be produced by using different inputs (process flexibility).
(6) *Option to growth*: An early investment, e.g., R&D, is a prerequisite or a link in a chain of interrelated projects, opening up future growth opportunities, e.g., a new product or process. A notable example is interproject compound options.
(7) *Interactions among multiple real options*: Real-life projects often involve a collection of various options. Upward-potential-enhancing and downward-protection options are present in combination. Their combined value may differ from the sum of their separate values, i.e. they interact with each other. They may also interact with financial flexibility options.

5. Correlation between renewable energy development policy planning and option type: case study of wind energy in Taiwan

This section describes the correlations between the government's RE policy planning and various options. First, company managers must often face major decisions involving capital investments; when facing investment decisions, they must select from among different strategies to maximize company profits or minimize losses. The following factors must be considered when making investment decisions:

(1) Several plans are made available for selection;
(2) Capital investment ordinarily accounts for a large amount of corporate funds;
(3) The return on many investments cannot be determined precisely at the time of investment; investment decisions are thus characterized based on risk and uncertainty;
(4) Capital investment normally impacts future corporate cash flow significantly, especially with investments that require a company to undergo many years of outward cash flow before inward cash flow is possible; and
(5) Once made, an investment decision is almost never recanted.

Similarly, when the government regards the development of RE as an investment decision, these five factors must be considered for the following reasons:

(1) The development of RE must similarly consider maturity, market competitiveness, future development potential, and degree of public acceptance of various technologies, with the technologies most worthy of promotion selected as a result;
(2) Less mature than the traditional fossil fuel generation technology, RE generation technology requires more governmental subsidies to reduce power generation costs. Moreover, since RE lacks economic incentives to attract private investment during the initial development period, the government must often sponsor demonstration systems to reduce uncertainty among product firms towards a new technology, and must also provide incentives and tax subsidies to induce private investment. The government must provide funding for such measures;
(3) RE generation technology requires heavy subsidization since it is not yet fully mature, yet cannot yield significant benefits. Similarly, demonstration systems, which also require heavy subsidization, cannot achieve an immediate payback when they are implemented. Therefore, RE policy planning is also prone to risk and uncertainty;
(4) Governmental subsidies and incentives to develop RE represent inward cash flow for private investing firms. Owing to both the time lag before governmental policies are promulgated and the fact that most subsidies require several years before fruition, the government also requires outward cash flow for several years before its policies yield benefits;
(5) Governmental agencies must implement their policies in conjunction with administrative or legislative units to be effective. Consequently, when the government drafts a certain development policy or promotion measure, that policy or measure is often impossible to revoke; revocation normally requires several years even when possible. Funds committed to this policy never achieve a return.

We can infer from governmental legal and promotional measures aimed at encouraging the development of wind power generation in Taiwan that governmental policy planning when formulating its RE development strategies complies with the following principles:

(1) *Growth development policy*: This policy is initiated when the technological maturity and competitiveness of power generation costs of a certain RE technology progress towards governmental established targets. Therefore, the government tends to continue or extend its current measures to allow a particular technology to become self sustaining. As for wind power technology, the "Taipower renewable energy purchase scheme" enacted by the Taiwan Government in 2003 provided incentives for wind power generation in the form of power purchases at fixed prices. Additionally, governmental revision of these operating guidelines in 2004 has continuously provided economic incentives to the wind power industry. This is representative of growth development policy.
(2) *Abandonment development policy*: When a RE technology reaches maturity and power generation costs make it commercially competitive, or when targets for the current stage are satisfied, the government may revoke current incentives and subsidies, facilitating technology development in a competitive market. As for wind power generation, the Taiwan Government promulgated three demonstration systems after issuing the "Regulations Governing Subsidies for the Establishment of Wind Power Generation Demonstration Systems" in March 2000. Owing to the effectiveness of both these demonstration systems and wind power generating costs that are commercially competitive, the MOEA halted its subsidies for demonstration projects in June 2004. This is representative of a abandonment development policy.
(3) *Contract development policy*: When power generation costs for a RE technology become commercially competitive, the government may then reduce subsidies to ease its fiscal burden. According to definitions of RE development progress, RE in

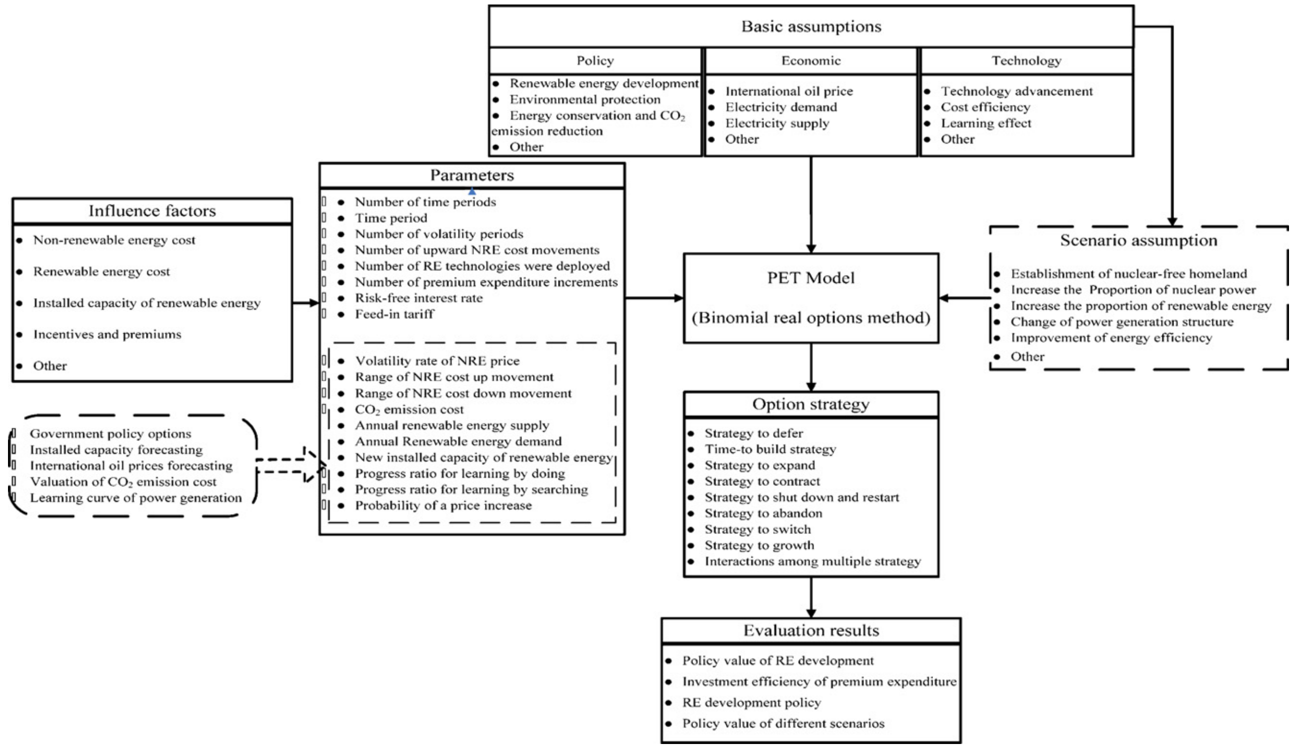

Fig. 2. Scheme of PET model.

Taiwan is currently in the demonstration and extension stages of development; the government thus continues to maintain subsidy measures for RE generating technologies. In the future, when a RE technology has developed to the point of promulgation in Taiwan, the government may adopt reduced incentives and subsidies for that RE, allowing that energy to develop on the open market. This reduction in incentives and subsidies is a contract development policy.

(4) *Expansion development policy*: If a RE technology has extremely low investment incentives, or the technology is still far from mature, the technology is still highly promising, or will be beneficial from the perspective of a globally competitive environment, energy security, or environmental protection. Therefore, the government may feel motivated to invest further in that technology in order to facilitate its growth. Consider wind power as an example. After subsidies for demonstration systems were ceased, although the government continuously provided economic incentives for wind power by purchasing electricity at subsidized prices, installed wind generating capacity fell significantly lower than the target set for 2010. Consequently, the Taiwan Government initiated the "Stage I Offshore Wind Power Generating Plant Establishment Program" in August 2007, passed the Renewable Energy Development Bill in 2009, and publicly announced wholesale power purchase rates for various RE technologies in 2010. Hopefully, such expanded support for developing wind power generation technology will encourage private parties to invest in offshore wind farms, ultimately expanding the island's wind power generating capacity even further. These programs represent an expansionist development policy.

(5) *Switch development policy*: If intending to simultaneously develop several RE technologies, the government will consider the future prospects of each technology, as well as select the main technologies to receive subsidies. By adjusting its prior use of funds, the government can steer resources to the most promising technology or technologies, thereby increasing the overall effectiveness of its policies. For instance, following the first and second National Energy Conferences, the Taiwan Government initiated the development of seven RE technologies via a three-stage short-/mid-/and long-term development program. Thereafter, the Executive Yuan reformulated the island's RE development program at the 2007 Industrial Technology Strategy Conference, and committed resources to primary and secondary development areas. The government has designated solar power, biomass energy, and wind power generation as the major short-term development items, and geothermal, fuel cells, and ocean energy as long-term development items. This strategy represents a switch development policy.

If the above policy plans are viewed as policy choices, according to the perspective of Trigueros [19], RE technology development policies of the government can be considered as options behavior during policy planning. The government has the following five options: option to growth, option to abandon, option to contract, option to expand, and option to switch. In sum, when policy makers must consider which options action will most effectively promote the development of RE technology, and then implement that option. This approach ensures that governmental fiscal resources are used most efficiently while avoiding unnecessary societal costs.

6. Options-based policy evaluation framework for developing renewable energy technologies

6.1. Basic concept of proposed framework

Policy planning and technological development of RE resemble R&D activities in that short-term, medium-term, and long-term goals that may require decades to achieve. Therefore, in addition to its inadequacy for investment valuation of energy projects [32], the traditional evaluation model fails to accurately reflect the value of RE technology in the highly volatile energy mar-

ket [33,34]. The value of an R&D investment project is rarely an immediately realizable return. Rather, profit is typically generated from future investment opportunities after successful R&D [28,35]. Hence, quantifying an investment opportunity is essential for estimating the value of an investment project. ROA is an effective means of measuring the value of a specific project precisely [24,36–39].

This study examines the government's RE industry development policy, in which planning actions originate from the perspective of fiscal and investment behavior based on the government's political (Policy), macro-economic (Economics), and technological development (Technology) considerations. The binomial real options pricing approach is used as a foundation for constructing the options-based policy evaluation model (PET model). This study first analyzes the uncertainty and risks faced by the government when formulating RE development policies, uses the analysis results to identify the main factors affecting policy-making and determine the main parameters required by the assessment model, and employs the binomial real options pricing approach and learning curve concept to construct a PET model. This model facilitates the drafting of RE development policies established by the governmental agencies and energy companies. Fig. 2 shows a framework scheme of the PET model. Additionally, many studies [40–44] confer that many factors affecting RE development include NRE costs, RE costs, R&D expenditure of RE, advances in RE technology, and RE demand. Those studies further demonstrated that the real options evaluation model is appropriate for evaluating the investment value of RE technological development. The analytical framework of the real options pricing approach facilitates our evaluation of uncertainty in policy planning and ability to determine accurately managerial flexibility in a constantly fluctuating investment environment. The framework also provides decision makers with an approach that effectively responds to fluctuating circumstances and making accurate decisions. Therefore, the research model in this study utilizes the real options pricing approach. Additionally, according to the above summary, many factors affect the development of RE. Therefore, based on an exhaustive literature review, the PET model of this study considers factors that influence NRE costs, RE costs, installed capacity of electricity generated by RE, and incentives and premiums.

6.2. Construction of PET model

The proposed PET model is constructed based on the theoretical framework of the binomial real options method. The theoretical foundation of this framework is summarized below. Sharpe [45] and Cox et al. [46] developed the earliest binomial options assessment models. Because most subsequent studies refer to the study of Cox et al., their model is subsequently termed the CRR model.

Flexibility of the binomial real options model makes it highly feasible for real options valuation since it can be adjusted to the specific conditions of a project. However, the model is limited mainly in that it may expend a considerable amount of computational power to achieve an accurate outcome. Using a binomial real options model initially involves starting with one or several options with times to maturity of less than or equal to T years. These T years are divided into a finite number of time periods of length Δt, while the next step involves creating a binomial tree with project values during these time periods. In the binomial lattice model, during each period, a situation is modeled in which the project value can either increase with a factor u or decrease with a factor d. If σ denotes the project's volatility, u and d are calculated as $u = e^{\sigma\Delta t}$ and $d = 1/u$. The binomial tree with one node for $t = 0$ where the project value without flexibilities, S, has been estimated. After time Δt, the project value is modeled as either

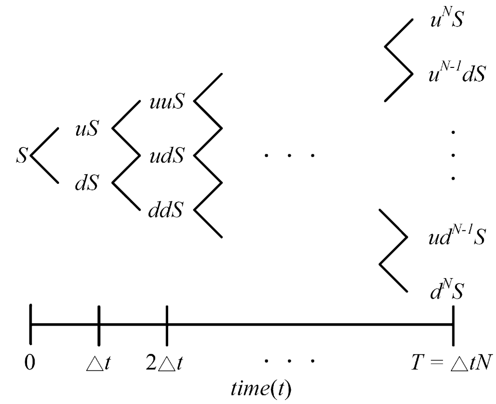

Fig. 3. Example of a binomial tree.

uS or dS; after another time period, there are three project value $uuS = u^2S$, $udS = duS$ and $ddS = d^2S$. This approach is continued until $T/\Delta t$ time periods have been added and our binomial tree is ready, as shown in Fig. 3. While this tree represents the possible values of the project without flexibility at different times, these values are used to estimate the option value. The project is valued flexibly by first examining the end nodes of the tree, at time $t = T$. For each node, i.e. n options, the option to exercise depends on the project value. For some end nodes, exercising any option may be undesired, but rather to merely continue as previously. Here, the option that maximizes the value of the project with flexibilities, c, is chosen due to the following formula:

$c_{node\ i}$ = max[Value of option 1 when $S = S_i, \ldots$, Value option n when $S = S_i$, S_i]

Once the values are calculated, decision makes can continue to calculate the values of the nodes for $t = T - \Delta t$. At these nodes, some options may be exercised (but not necessarily the same options as before), and decision makers can choose to exercise any of these options; otherwise, continue without exercising. If decision makers choose to exercise an option, the project value with flexibilities is calculated using the value of the project without flexibilities in the same node and adding the extra value by exercising the option. However, if decision makers choose to continue without exercising, they end up in any of the two nodes at $t = T$ having edges to the node under examination; in addition, the value of continuing depends on the values in these two nodes. However, the two values cannot be simply averaged and discount the average back at time Δt to derive the correct value. Importantly, a risk-free probability must be found and a weighted average used before discounting.

Closely examining modifications in the proposed PET model reveals that international oil prices generally correlate with NRE prices, e.g., fossil fuel prices. Lower NRE prices diminish the underlying reasons for developing RE. Conversely, excessively high international oil prices strengthen the underlying motivations for developing RE technology. The volatility of NRE prices may thus be viewed as the probability of successfully developing RE technology. Fig. 4 illustrates the variability in the NRE cost derived by binomial stochastic process to simulate the variability of NRE costs. NRE costs follow GBM, which can be approximated via a multi-period binomial process in which the uncertainty of the NRE cost may be represented by two possible outcomes at each time step, i.e. either an increase or decrease. Let $S(k,i)$ denote the variability in NRE cost with k periods elapsed in the RE development planning lifetime and i upward cost movements to date. For an initial NRE cost represented by $S(0,0)$, the cost for the next period is stochastic and can be valued in the following two ways:

$$S(1, 1) = uS(0, 0), \text{ with probabilty is } p$$

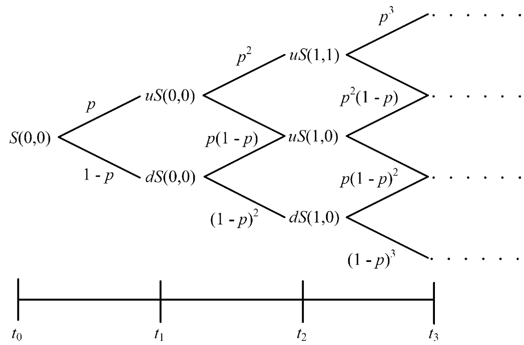

Fig. 4. Binomial lattice stochastic process.

$S(1,0) = dS(0,0)$, with probabilty is $1 - p$

Generally,

$S(k+1, i+1) = uS(k, i)$, with probabilty is p, $0 \leq k \leq T$ and $0 \leq i \leq k$

$S(k+1, i) = dS(k, i)$, with probabilty is $1 - p$, $0 \leq k \leq T$ and $0 \leq i \leq k$

$$\Rightarrow S(k, i) = S(0,0)u^i d^{(k-i)}, \quad 0 \leq k \leq T \text{ and } 0 \leq i \leq k$$

where, S is the non-renewable energy cost (NRE cost); T is number of time periods; n is number of volatility periods; k is time period, $0 \leq k \leq T$; i is number of upward NRE cost movements, $0 \leq i \leq k$; α is risk-free interest rate; p is probability of a price increase, $p = {}^{e^{\alpha(T/n)} - d}/_{u-d}$; μ is range of NRE cost upward movement, $u = e^{\sigma\sqrt{T/n}}$; d is range of NRE cost downward movement, $d = {}^{1}/_{u} = e^{-\sigma\sqrt{T/n}}$; σ is volatility rate of NRE price.

6.3. Static analysis of policy value for PET model

A contrast is made with the PET model, in which determining the policy value of developing RE technology within the ROA framework initially requires estimating future cash flows for a RE technology devised by Davis and Owens [42]. Positive cash flows, in the form of consumer cost savings, arise when RE technologies are implemented and consumers are provided with electricity at a cost lower than that of NRE technologies. Integrating RE promotion and increasing NRE costs facilitates the adoption of RE technologies in the marketplace, giving rise to lower cost suppliers of electricity. The surplus is the cost savings passed onto consumers, as achieved by replacing the higher cost of NRE electricity with the lower cost of RE electricity. To simplify the initial analysis, in contrast with Davis and Owens [30], the proposed model in this study does not incorporate technical risk. Alternatively, the options value of developing RE is determined by assuming policy planning success, but poses market risks, i.e. allowing for stochastic NRE costs. Based on a binomial stochastic process, this study simulates the variability of NRE costs, in which the data provides the basis for developing a policy evaluation model. Additionally, the magnitude of reduction in the cost of generating electricity with RE is simulated using a cost efficiency curve of generated power. Finally, the PET model is developed using the binomial real options pricing approach.

Additionally, this study uses supply and demand curves and the concept of consumers' surplus to explain the fluctuations in cost savings. Notably, fluctuations in producers' surplus and total societal benefit are not considered here. Three situations affect cost savings:

(1) When declining international oil prices lower the cost of fossil fuel-generated power ($S_{F1} \to S_{F2}$), the cost gap between fossil fuel-generated power and RE (S_R) grew increasingly large. Doing so increases the demand for traditional fossil fuel-generated power ($q_1 \to q_2$), and a negative cost savings gradually increases (□*abcd*→□*abef*), ultimately yielding a negative policy benefit value (Fig. 5(a)).

(2) With a rising cost of traditional fossil fuel-generated power ($S_{F1} \to S_{F2}$), the cost gap between fossil fuels and RE (S_R) diminishes, and the demand for traditional fossil fuel-generated power falls as well ($q_1 \to q_2$). Doing so causes a negative cost savings to gradually drop (□*abef*→□*abcd*). Assume that the cost of traditional fossil fuel-generated power rises continuously ($S_{F2} \to S_{F3}$), and is ultimately higher than the cost of power from RE (S_R). Consequently, the demand for traditional fossil fuel-generated power diminishes ($q_2 \to q_3$), ultimately yielding a positive cost savings (□*abcd*→□*abgh*) and a positive policy benefit value (Fig. 5(b)).

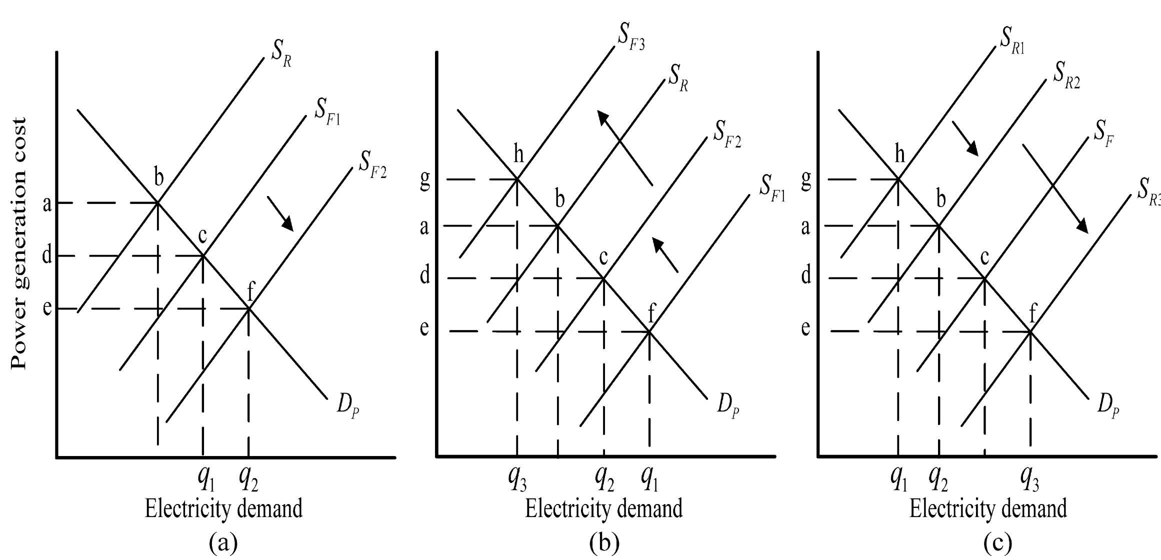

Fig. 5. Schematic diagram of cost savings change.

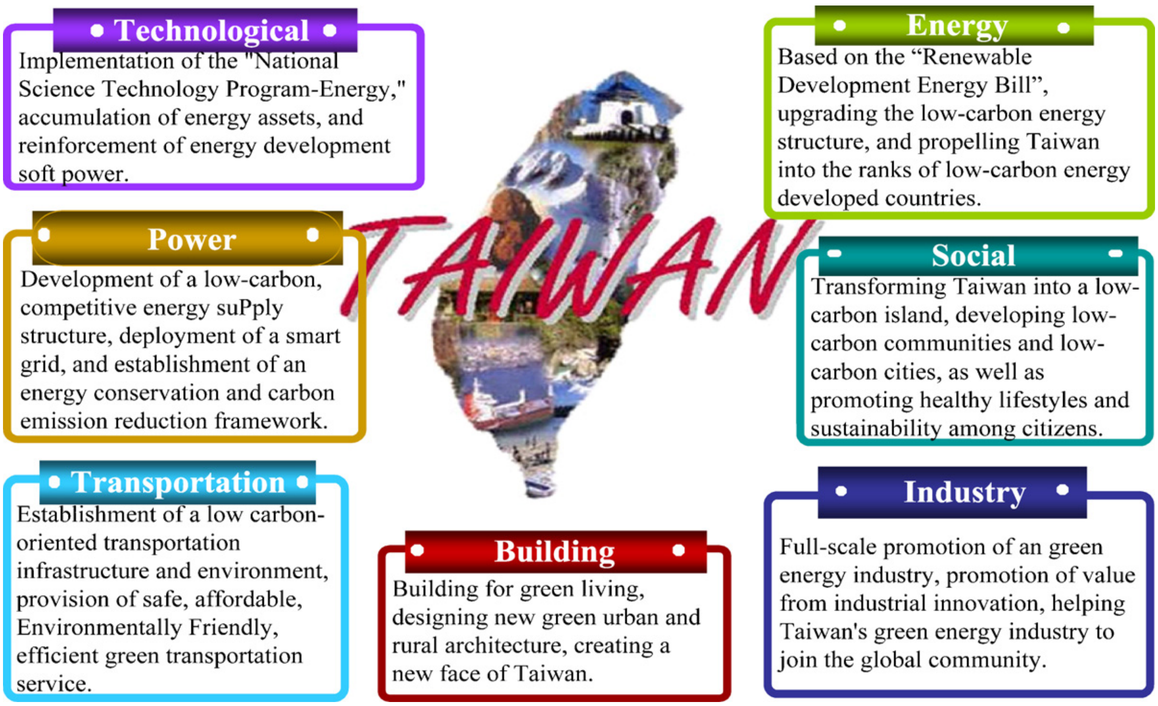

Fig. 6. Idealized vision of a low-carbon society for the 21st century.

(3) Advances in RE technology lowers the cost of RE ($S_{R1} \rightarrow S_{R2}$) and gradually diminishes the cost gap with traditional fossil fuel-generated power (S_F). Consequently, the demand for RE increases ($q_1 \rightarrow q_2$), and the negative cost savings gradually diminishes ($\square cdgh \rightarrow \square abcd$). When the technology continuously improves, the cost of RE decreases steadily ($S_{R2} \rightarrow S_{R3}$), ultimately falling below the cost of fossil fuel-generated power (S_F). Moreover, the demand for RE increases steadily ($q_2 \rightarrow q_3$), ultimately yielding a positive cost savings ($\square abcd \rightarrow \square cdef$) and a positive policy benefit value (Fig. 5(c)).

In summary, the PET model developed in this study is based on the theoretical foundation of the ROA, in which the factors that influence the development of RE technology are considered. The proposed model largely reflects how fluctuations in the price of traditional fossil fuel-generated power affect RE. Also, the binomial real options pricing approach is adopted to elucidate the effect of fluctuations in the cost of fossil fuel-generated power. Meanwhile, the proposed model accounts for decreases in the cost of RE generation due to the continued provision of subsidies or technology advances. In addition to evaluating the benefit value of RE development policies, this information is also used to determine subsidy duration and the cost-benefit breakeven point. Moreover, the proposed model is used to draft development policies for the upcoming year. Furthermore, modifications in various RE policies, technology status, and energy markets affect the generating costs of a power company, installed RE capacity, subsidy inputs, and development policy planning. Given these factors, scenario analysis is performed to derive assumptions concerning possible situations in the future. This study thus adopts the proposed PET model to investigate the impacts of different scenarios, make comparisons with the basic scenario, and analyze differences in policy planning under various scenarios. Finally, this study drafts relevant measures for reference purposes and submits conclusions and recommendations accordingly.

7. Conclusions

Countries worldwide increasingly prioritize sustainable development practices and the development of a green energy sector. Similarly, the Taiwan Government emphasizes energy conservation measures to reduce carbon emission levels. To actively encourage the development of a RE industry, the government must assess precisely the investment benefits of various development policies, enabling it to evaluate the effectiveness of various policies. However, many uncertain factors may afect RE development policies, and traditonal assessment models can neither simultaneously consider these factors nor determine the management flexibility value of policy maker responses to projected future changes. Therefroe, traditional assessment models fail to adequately assess the benefits of RE development policies that are characterized by managerial flexibility, multiple choices, and R&D.

Based on ROA, this study constructs a PET model that can incorporate such internal factors as governmental policy-making actions and such external factors as oil price fluctuations and other changes in the investment environment. By applying an appropriate options strategy, the proposed PET model can help reduce policy implementation costs, enhance policy performance, and facilitate an estimation of substantial benefits brought by specific policies. Such measures can enable the government to subsidize industrial development, increase firms' autonomous R&D capabilities, accelerate local industrial development, and reduce costs. The model can further help avoid excessive and redundant subsidies that increase the government's fiscal burden. We therefore recommend that the government and relevant energy units utilize the options strategy planning concept when drafting RE development policies and promotion measures. Doing so helps to achieve optimal energy conservation and carbon reduction results, ultimately allowing us to realize a low-carbon society of the future (Fig. 6).

Moreover, RE is characterized as environmentally friendly, diverse in sources, and predictable costs that are not linked to fluctuations in international oil prices. Industrialized countries have

thus prioritized implementing RE applications. After reviewing successful RE development experiences in various countries, this study devises three major promotional strategies to promote RE development.

7.1. Feed-in tariff and guaranteed purchase

During the initial RE development period, the public power utility should be legally required to purchase electricity produced from RE as the first priority. Doing so will allow environmentally friendly energy to enter the market and provide sufficient incentives for RE providers, thus encouraging private investment in RE power generation. By considering the promotion of wind power in Germany as an example, the 1991 "Electricity Feed Law" (EFL) stipulated that public power utilities must purchase power generated by RE at a price of 90% of the average electrical sale price, or approximately 0.16–0.17 (DM/kWh). This amount is markedly higher than the purchase price of 0.1 (DM/kWh) for conventionally generated electricity. Furthermore, the 2000 "Act on Granting Priority to Renewable Energy Sources" similarly prescribes that electricity shall be purchased for a fixed price of 0.178 (DM/kWh) during first five years of operating the wind power equipment. Thereafter, although the purchase price may be gradually loaded in view of the amount of generation, the lowest purchase price must be paid for in 20 years [47].

7.2. Subsidies for purchasing project equipment

During the initial period of RE development, the Taiwan Government may earmark project funding to purchase some equipment, subsequently easing investors' investment costs and encouraging private investment by functioning as an additional incentive besides fixed purchase prices. By considering the German government's 250 MW wind power project as an example, the Taiwan Government provides subsidies of up to 25% of equipment investment expenses to wind generation enterprises. For generating systems connected to the grid, power fed to the grid may receive an additional subsidy of up to 0.06 (DM/kWh) [47].

7.3. Expedited energy price rationalization and market opening

Owing to the unique nature of energy and the complex complementary and substitutability factors between different forms of energy, in line with the market mechanism, the government should design an appropriate energy price structure that reflects internal costs (e.g., fuel costs) and non-market external costs (e.g., the cost of carbon dioxide emission levels). This energy price structure should ensure that energy prices are rational, complete, accurately represented, and fairly implemented. Doing so not only facilitates economic and environmental benefits, but also respects the energy structure and industry structure determined based on consumer preferences, while safeguarding the legitimacy of choices that reflect a societal consensus and economic incentives. Meanwhile, this price structure will further accelerate the effectiveness of energy enterprises, improve the structure of the energy industry, encourage public welfare, and make the energy industry more sustainable, effective, and environmentally friendly.

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